AN AXIOMATIC DESIGN SOFTWARE TOOL FOR DECISION MAKING DURING THE PRODUCT CONCEPTUAL DESIGN PHASE

Valdeon Sozo, Ms. Eng.
Multibras S/A Eletrodomésticos
Dona Francisca, 7200
Joinville - SC - Brazil - 89219-900
valdeon_sozo@multibras.com.br

Fernando A. Forcellini, Dr. Eng.
Federal University of Santa Catarina
Campus Universitario - Trindade
Florianópolis - SC - Brazil - 88010-970
forcellini@nedip.ufsc.br

André Ogliari, Dr. Eng.
Federal University of Santa Catarina
Campus Universitario - Trindade
Florianópolis - SC - Brazil - 88010-970
ogliari@nedip.ufsc.br

Abstract. The objective of the product conceptual design phase is to provide one or more product concepts in order to meet customer requirements, that are translated as wishes from identified problems or project requirements. These concepts, named alternative concepts, are most of the time the power of the design process due to the high quantity of them and on the other side, the weakness, due to the hard work to address the whole alternatives, because the criteria to evaluate them are not always evident. By means of a critical analysis of the decision making process regarding concept selection, it was verified that the different methods in literature claim for clarity and simplicity of the design and, most of them present design specifications as criteria that, logically will be different from project to project. Thus, one may conclude that there are criteria and orientations to be followed during the decision making process. However, they are almost always domain dependent, having no set of design specifications that could be used for all design fields. Through an axiomatic design analysis, was verified that the design axioms were considered as quality measures of the design being applicable for all design fields, (Suh, 1990) but the way they were presented, either to their definition or lack of measuring metric, became somehow difficult its application in some cases. These axioms, were then redefined into criteria or goals to be optimized and by adding new metrics was possible to perform suitable evaluations in order to check their meeting, providing a broader axiomatic design application. Therefore, in this work was proposed a decision process for selecting alternative concepts regarding the new established metric that, implemented in a computational tool provides better results for problems that come up during the product conceptual design phase.

Keywords: *axiomatic design, conceptual phase, decision making, product development.*

1. Introduction

Although design practices in different fields appear to be distinct from each other, all design fields use a common thought process and design principles. In this sense, there are many ways to approach the theme. The axiomatic approach is one of them, providing a general theoretical framework for all design fields, including mechanical design. (Suh, 1995). The researches in axiomatic design began in 1997, by the professor *Nam P. Suh*, from *MIT (Massachusetts Institute of Technology*). According to Suh, the axiomatic approach starts with a different premise: that exist generalized principles that govern the intrinsic behavior of the design process, called axioms. The axioms are general principles or self-evident truths, that can not be derived or proven to be true, except that there are no counter-examples or exceptions.

Another proposition to the product development process, called Consensus Model (Ogliari 1999) and (Ferreira, 1997), is being defined has a four stage step method: informational design, conceptual design, embodiment design and detailed design. This proposal was established having as bases the methodologies proposed by Back (1983), Pahl & Beitz (1996), Ullman (1992), Blanchard & Fabricky (1990), and others.

Although authors approach design in different ways, their orientations permit to conclude that the design can be understood as a process where the objective is to convert information that characterize the needs and requirements of the product into knowledge about the product. In this process, many decisions must be taken and the amount of information involved is quite big. There are many alternatives that can be generate and the criteria to evaluate them are not always evident. Analyzing the methodologies at the literature expressed by the Consensus Model, it is possible to verify that criteria applicable to many design fields are not contemplated, existing just restrict orientations for specific domains. The axiomatic approach through the design axioms supply these criteria to be used in all design fields (Suh, 1990).

So, researches involving the establishment of criteria for decision making are contributions to the product development process, motivating the realization of this work. The purpose here is to use the axiomatic approach to establish criteria to be applied to the conceptual design phase, resulting in a decision making process susceptible to computational implementation, aiming to support the human judgement but never substitute it.

2. The conceptual design phase

The conceptual design phase is considered the most important phase in the product design process, because the decisions taken in this phase make a broad influence in the results of the subsequent phases (Back & Forcellini, 1997).

Through an analysis of the mains activities pertinent to this phase, it is possible to observe that criteria for decision making are established as orientations or method. They reflect systematic efforts that try to guide the project team in a certain direction and, most of the time, they take as goals the design specifications.

So, the conclusion is that do exist criteria and orientations to be follow while selecting concepts. However, these are many times domain dependent and present a high level of subjective associated.

To eliminate this deficit was performed some researches related to the axiomatic approach, since its axioms provide ways to help the decision making process.

Thus, through the axiomatic design approach it is intended to introduce criteria in such a way that they could be used in several design fields.

3. Axiomatic approach

3.1. History

The axiomatic design begins with the premise that exist generic principles that govern the intrinsic behavior of the design process. The axioms are general principles or self-evident truths, that can not be derived or proven to be true, except that there are no counter-examples or exceptions.

The researches in axiomatic design began in 1997, by the professor *Nam P. Suh*, from *MIT (Massachusetts Institute of Technology).* The author has identified common elements of many successful projects in industries and universities and has generalized these common elements into twelve "hypothetical" axioms. These ones were reduced to six "hypothetical" axioms and six corollaries, leading to his first work (Suh Beel & Gossard, 1978) which presents the axiomatic approach application to manufacturing systems. Through many analysis of the axioms, they were finally reduced in two, resulting in new publications: Suh et all, (1979) and Suh (1984). Among his publications, it is possible to stand out his two last books, *The Principles of Design* (Suh, 1990) and *Axiomatic Design: Advances and Applications* (Suh, 2000).

3.2. The selection of concepts through the Axiomatic Approach

Design can be formally defined as a creation of solutions, synthesized in the form of products, process or systems that meet customer needs. In the case of axiomatic approach, this is realized by the appropriate selection of DPs for meeting FRs. This selection is based on the mapping between FRs, in the functional domain, and DFs, in the physical domain (Suh, 1990). This mapping is not unique and, because of it, there are many alternatives that can be elaborated. The design axioms provide the criteria that this mapping must meet to produce a "good" design and offer a base of comparison and selection for design solutions.

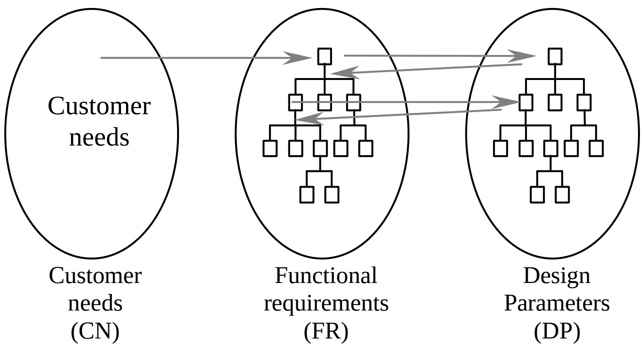


Figure 1 – Mapping between axiomatic approach domain.

The first axiom is the independence axiom: "Maintain the independence of the functional requirements". In an acceptable design, the mapping between FRs and DPs must be such that a perturbation in a particular DP must affect only its referent FR. (Suh, 1990)

The second is the information axiom: "Minimize the information content of the design". Among all the designs that satisfy the first axiom, the one with minimum information content is the best. (Suh, 1990) In this way, designs that minimize the number of requirements, have a small number of functional requirements and restrictions, show integrated parts preserving its functional independence, use standard and interchangeable parts and show symmetry as much as possible, will lead to designs that have a reduced information content, that means, higher probability of success.

So, as proposed by Suh the axiomatic approach establishes design selection by checking the meeting of axioms, where at first one must perform an evaluation of the design alternatives based on the independence axiom, and after, among all the solutions that has satisfied it, will be evaluated against the information axiom.

3.3. The design matrix

Defining a FR vector having the elements as functional requirements and other DP vector, having its elements as design parameters, design will be so to select the appropriated set of DPs in such a way that the Eq (1) be met.

$$\{FR\} = [A] \times \{DP\} \tag{1}$$

The {FR} vector expresses what is desirable in terms of design goals and, the multiplication of the matrixes [A]{DP} expresses how it is intended to meet the functional requirements of the project. The matrix [A] is called design matrix and can be seen at the Fig (2).

The design matrix elements A_{ij} can take two forms: numeric values or letters. The representation by letters is used to simply indicate a dependent relationship between FRs and DP, but the specific relation has no interest. An "X" means that there is a relationship. An "O" means that there no relationship. By numeric elements the design matrix describes the same relationships, having the possibility to describe it through equations or simply by numbers that models mathematically the physical relationships.

In the axiomatic approach the kind of the relationship will defined the solution type.

There are three types of solution. The first is the one that meets the first axiom, and happen when [A] is a diagonal matrix, as described by Fig (1a). This solution is called uncoupled.

The second never meets the first axiom. In this case the solution is called coupled and it is described by Fig (2b).

$$\begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \qquad \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \qquad \begin{bmatrix} A_{11} & 0 & 0 \\ A_{21} & A_{22} & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

(a) (b) (c)

Figure 2 - Design matrix according to the axiomatic design approach.

The third one is called decoupled and it is represented by Fig (2c). In this case, the FRs independence can be ensured if the DPs are disposed in the design matrix in such a way that form triangular matrix. In this case, the meeting or not to the first axiom depends on the order that the DP will be changed.

Therefore, in the axiomatic approach the evaluation of alternative concepts is done based on the relationship between FRs and DPs, demonstrated by the design matrix, which will indicate if the first axiom will be met or not. If there might be many solutions that meet the first axiom, it is necessary to use the second axiom as the selection criteria for the final decision.

4. Axiomatic approach reformulation

As originally proposed by Suh, the axiomatic approach establishes concept selections by checking the meeting of the axioms. The Figure (3) shows this process, where at first it is necessary to perform an evaluation of the alternative concepts against the independence axiom and, only the alternatives that have met it, will be evaluated with the information axiom.

As one can observe, the coupled alternative are dismissed. Thus, the evaluations against the first axiom can be seen as go / no go tests. Suh (1990) states that projects that do not meet the first axiom could not be produced due to the coupled relations between FRs and DPs and, for this reason should not be considered. However, many authors Dimarogonas (1993), Ringstad (1997) for example, do not agree with Suh, stating that the absolute satisfaction of the first axiom could not be achieved for all projects, especially in the cases that the components are thoroughly predetermined, reducing the project freedom. In these cases, the axiomatic approach application, as originally stated by Suh, would no be possible because the complete satisfaction of the first axiom probably will not be achieved and, as proposed by the author, there is a meeting obligation without trying to maximize it.

For the decoupled solutions there are "R" and "S" metrics (Suh, 1990) to evaluate against the first axiom, but there is no metric to evaluate against the second axiom. Thus, the alternative selection is limited to the first axiom. The uncoupled solutions, do not need to be evaluated against the first axiom, because they are uncoupled ones. Their evaluation is done only through the "I" metric (Suh, 1990) based one the second axiom.

Even if the axiomatic approach still does not present a common agreement among the authors, mainly about evaluations related to the first axiom, the results demostrated at the literature (Sozo et all, 2001) have proved the great axiomatic approach potential.

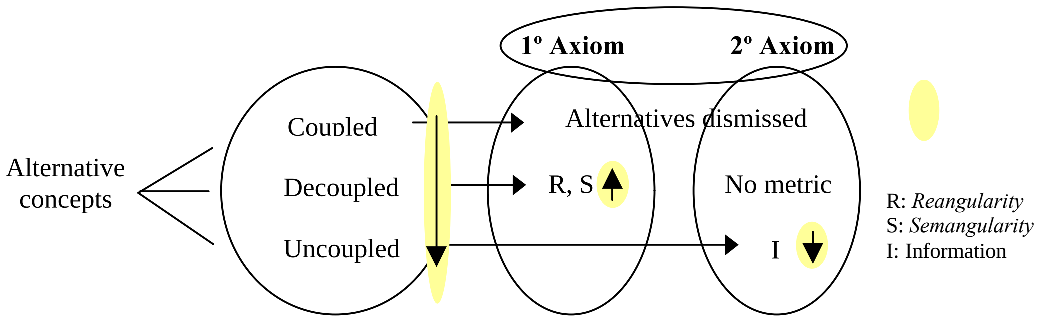


Figure 3 - Axiomatic approach by Suh (1990).

Thus, it is proposed an axiomatic approach reformulation especially relating to the first axiom, in such a way that the axiom could be used as criteria to be maximized on the decision making process.

So, the axioms proposed by Suh are here reestablished as follow:

First criteria: among many design solutions, the one that has the lower level of functional dependence will be the best.

Second criteria: among many design solutions, the one that has lower level of information content will be the best.

The need to reestablish the axioms is justified below:

- due to the non agreement among the authors for naming the axioms as such, in this work the axioms were named as criteria, even if were not found examples at the literature proving that the axioms are not valid. It is not the objective of this work to check the axioms validity, but only used them, because their potential was already proved through many examples published at literature. (Sozo, 2002)

- due to the unavailable application of axiomatic approach when the first axiom could not be met. The first axiom is so redefined as a criteria to be maximized, similarly with the second one.

Therefore, it is proposed the use of axiom as goals, to be achieved by maximizing or minimizing metrics that will measure their satisfaction during the design process. The approach so proposed is shown at Fig (4), where: *"Tc", "Ai" e "I"* are metrics to be used for evaluating the alternative concepts and detailed on the next items.

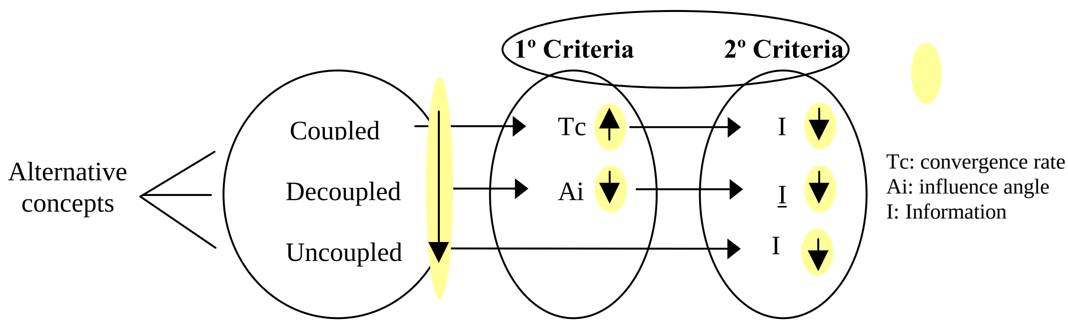


Figure 4 - Proposed approach.

To choose the best alternative concept (or design solutions) first it is necessary to classify the alternatives as coupled, decoupled and uncoupled, equally as proposed by Suh. Such classification is determined by the relationship between FR and DP, described by the design matrix. For each classification there will exist metrics to be optimized maximizing the design axioms satisfaction.

The arrows position indicates the direction to be followed, that is, when it is necessary to compare alternatives classified at different types, one should choose at first the uncoupled ones, followed by the decoupleds, and last, the coupled ones. Relating to the metrics, the arrows direction indicates if they should be maximized or minimized, that is: the best solution, if the alternatives are coupled, will be the one who has the bigger value for *Tc* and the lower value for *I*. If the alternatives are decoupled the one that should be chosen is the one that has the lower value for *Ai* and also for *I* and, if they are uncoupled the best will be the one that has the lower value for the metric *I*, only. These metrics will be defined later.

About the evaluation of coupled and decoupled solutions it is important to mention that, if the alternatives are coupled it is better to choose the one with higher independence level even if it has a higher information content, because it will need less interactions to meet the requirements and has low operating complexety. (Frey, Jahangir & Engelhardt 2000).

If the alternatives are decoupled it is better to choose the one with lower information content even if it has lower independence level, because the higher probability of success due to the low information content compensates the task of changing the DP in a specific order. Therefore, the second axiom is prioritized here, since the first was already met by the decoupled alternatives.

Such prioritizing, sometimes to the first axiom sometimes to the second, are shown in Fig (4) by means of having

Tc and *Ai* metrics underlined.

4.1. Evaluation metrics for the first axiom

Suh (1990) proposed two metrics to evaluate the functional independence level for a design solution, named *Reangularity* (*R)* e *Semangularity (S)*. According to the author to completely define the functional independence level for one design solution one should consider the angle between the axis that represents the DPs and their alignment with the axis that represent the FRs, expressed by R and S, receptively.

However, the author did not mention how they should be combined or used in such a way to indicate the best alternative among others design solutions.

This problem could be solved using another way to measure the functional independence level, as proposed by the authors Arcidiacono, Campatelli e Lipson (2001). Differently from Suh these authors propose another metrics to evaluate coupled and decoupled solutions.

Let's consider one coupled design solution where the FRs and the design matrix [A] are known and, it is necessary to establish the DPs to meet the FRs. Such situation can be compared to an equation system having FR and A where it is desirable to get DP. (See Eq (1))

Since the design matrix elements do have different physical units between each other, the DPs values could not be calculated by a single step through linear algebra, but require an iterative process.

For coupled designs the coupling level is defined as the difficulty of adjusting DPs to meet FRs. This difficulty is measured as a function of the number of iterations required so solve the system. Iterations here means the feedback on the DPs values to meet the FRs. However, to calculate the system's rate of convergence is easier because it is inversely proportional to the number or interactions and, contemplates the coupling level of the system as well. Thus, to calculate the rate of convergence the authors used the Jacobi method, chosen for its simplicity.

Than, it is possible to calculate the convergence rate, named *Tc* in this work, using Eq (2) defined by Young (1971):

$$Tc = \ln\left(\frac{1}{S_G}\right) \tag{2}$$

Where S_G is the spectral radius of the G matrix, that is, its maximum absolute eigenvalue. As the convergence rate is inversely proportional to the coupling level of the system, one may conclude that the better the *Tc* value the better will be the alternative being considered. Thus, it is possible to use this metric as a selection criteria.

However, the *Tc* metric can be applied only for coupled solution, because for decoupled solutions there is no need for iterations to find out the right values for the DPs in order to meet the FRs.

For decoupled solutions Suh (1990) proposes the metric R and S. Thus, the same problem as for coupled solutions will occur, that is: when selecting the best solutions among two, A and B, A could be selected if R is the criteria. But on the other side, having the S metric has the decision criteria, it is possible that the solution B should be the one to be selected. Such impasse could be solved with the metrics proposed by Arcidiacono, Campatelli e Lipson (2001), who define a different metric to measure the functional independence level for decoupled solutions, by means of the average of the existent angles between each FR and DP. The smaller the angle between FR and its respective DP the smaller the system coupling level, because the remaining DP will have smaller influence on this FR.

Although the authors have defined this metric for decoupled solutions, it can be used to measure the independence level for coupled solutions too, specially due to the complexity for calculating Tc metric.

This influence angle, named *Ai* in this work, can be mathematically expressed through Eq (3), where the symbol "$\angle$" express the angle between vectors.

$$Ai = \frac{\sum_{i=1}^{n} FR_i \angle DP_i}{n} \tag{3}$$

The vectors of the DP axes are formed by the design matrix columns, while the vectors of the FR axes are formed by the columns of an identity matrix, because the FR by, definition, must be independents of each other.

The angle between two vectors, each one having "n" elements can be calculated by Eq (4):

$$FR_i \angle DP_i = a\cos\left(\frac{FR_i \cdot DP_i}{|FR_i|.|DP_i|}\right) \tag{4}$$

Therefore, by adding the Tc and Ai metrics into the axiomatic approach it was provided suitable criteria for selecting coupled and decoupled designs based on the first axiom. The metrics need for evaluation relating to the second axiom will be presented next.

4.2. Evaluation metrics for the second axiom

The second evaluation criteria is based on the information axiom: "among many design solutions the one that has the lowest information content will be the best". Suh (1990) defines the information content as a measure of the information needed to meet a specific FR. If the task is established in such a way that it could be met with no previous information, then the probability of success is equal to the unity and the information required is null.

Suh (1990) proposes only one metric to determine the information content and it is dedicated only to uncoupled solutions. The information content for coupled and decoupled solutions can not be calculated with the same procedure used for uncoupled solutions, due to the existent interrelationships between functions, that will lead to different results. (Frey, Jahangir & Engelhardt 2000) e (Suh, 1900)

The metric that will be used in this work will be that proposed by the authors Frey, Jahangir & Engelhardt (2000) that is originally dedicated to calculate the information content for coupled and decoupled solutions, but allows calculating the information content for uncoupled solutions as well.

Similarly to Suh (2000) the authors establish that the information content be determined as a measure of the probability of success while meeting FRs. In uncoupled solutions each FR is affected only for its respective DP. However, in coupled and decoupled solutions one must consider the influence of the rest of DP on the FR being analyzed.

Aiming at determining the information content taking account this influence, will be considered the case where there are only two DPs, which are probabilistic independent and uniformly distributed over their specifications. In this case, the joint density function is uniformly distributed over the range described by the system tolerances.

By definition, the design range can be represented as a set of point on the design parameter space that satisfy all the tolerances on the functional requirements. If the bilateral tolerance on the jth FR be represented as δFR_i , then each design tolerance can be represented by two constraints in the form of linear inequalities. These constraint together define the design range as shown by Fig (5a) taking shape of a n-dimensional polyhedron, having or not finite volume. The equations at the Fig (5a) came from Eq (1) and have been mathematically changed with the objective of establishing the DP based on FRs.

Similarly to the design range, the system range can also be described as a set of point on the design parameter space specified by the system tolerances that will be used to meet FRs and, is determined in the same way. Thus, if the bilateral tolerance on the ith DP be represented as ΔDP_i, the system range will be a rectangle having sides equal to $2\Delta DP_i$.

The intersection of the system range and the design range will define the common range, which will be a n-dimensional polyhedron too, having finite volume smaller or equal to the system range. The Fig (5b) describes the system range, the design range and the common range, used to calculate the information content of a design solution.

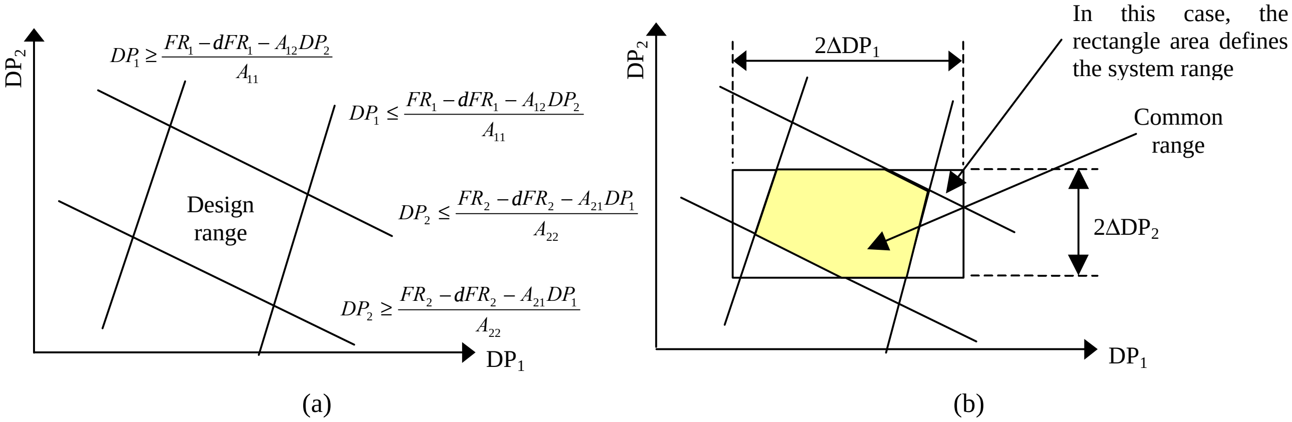


Figure 5 - (a): Design range representation for coupled solutions through convex polyhedrons on the bi-dimensional space. (b): System range and common range representations.

Therefore, the information content of a design solution having DPs with uniform probability distribution can calculated as the logarithm of the volume of two n-dimensional polyhedrons, where n represents the number of DPs and V() represents a set volume in the n-dimensional space.

$$I = \log\left(\frac{V(\text{system range})}{V(\text{common range})}\right) \tag{5}$$

Eq (5) can be viewed as an extension into n-dimensional space of the Eq (1) given by Suh (1990) where the DPs values, when determined as a function based on the FRs and the design matrix, will define the design range and, when determined by the system capability, will define the system range.

To evaluate Eq (5) it is necessary to calculate the system range volume and the common range volume. The volume that describes the system range in the form of a convex polyhedron in $\Re^n$ can be obtained through Eq (6), where the bilateral tolerance of the i^{th} DP is represented as ΔDP_i.

$$V(systemrange) = \prod_{i=1}^{n} 2\Delta DP_i \tag{6}$$

To automatically calculate the common range volume, will be used the Theorem proposed by Lasserre (1983). Given a convex polyhedron being defined by the set of linear inequalities $Ax \leq b$ the volume of a convex polyhedron that meets such inequalities is calculated by Eq (7):

$$V(n, A, b) = \frac{1}{n} \sum \frac{b_p}{|A_{pq}|} \times V\left(n-1, \tilde{A}, \tilde{b}\right) \tag{7}$$

where $\tilde{A}x \leq \tilde{b}$ is the system resulting from removing x_q from the system $Ax \leq b$, by casting the pth inequality as an equality.

Thus, Eq (5) and Eq (7) give an overall vision of the algorithm to calculate the information content for coupled and decoupled solutions with uniform distributed DPs. For practical implementation, there exist a bigger number of details. However, due to space restrictions, such details and the algorithm to calculate the common range volume will not be illustrated in this work. For further information it is suggested the reference Sozo (2002).

5. Case study: a cool range door

To illustrate the application of the decision making process proposed in this work for concept selection, an analysis related to the conceptual design phase of a range, one of the most popular products in our homes, was performed. Through this application it is intended to demonstrate the functionality of the proposed tool for concept selection during the conceptual design phase.

The most higher temperatures on the product occur inside the oven: around 280ºC. The high temperature certainly will cause grave burns on customer, thus requesting a suitable and efficient isolation at the oven door. But, besides the requirements above mentioned, an oven door must meet other requirements. Their functional requirements are on Tab (1).

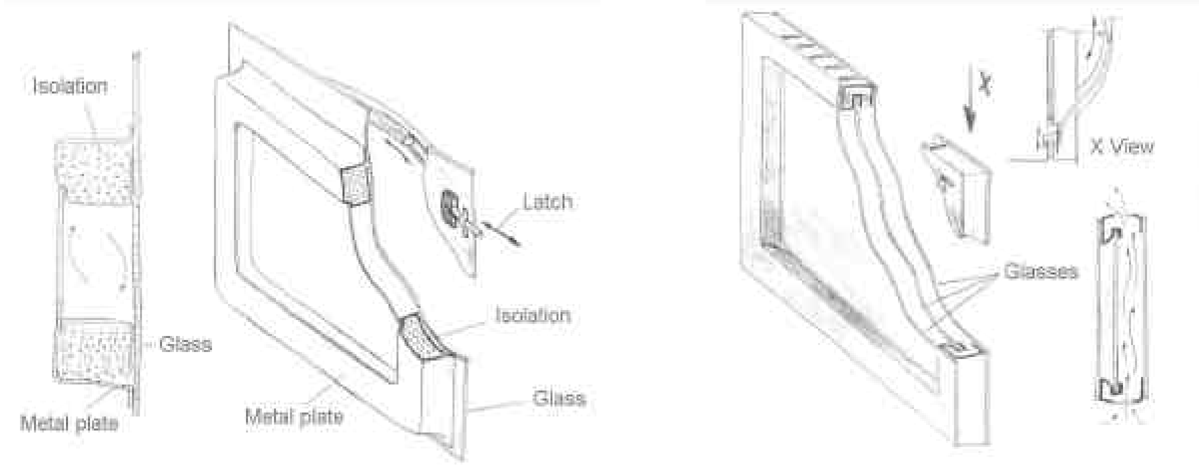
Table 1 - FRs specifications.

	Target value	Tolerance
FR_1: Isolate temperature	80°C	+5°C
FR_2: Allow inside visualization	50%	±5%
FR_3: Possible to be locked	5000cycles	±500cycles
FR_4: Resist to the utensil weigh	0,005m	+0,002m
FR_5: Stop gas leakage	10N	±0,5N

To meet the FRs mentioned above and solve the problem some solutions were prepared. They are defined in terms of DP by Tab (2) and illustrated in Fig (6).

Table 2 - DPs specifications.

Solution A	Target value	Tolerance	Solution B	Target value	Tolerance
DP_1: Isolation thickness	0,05m	±0,005m	DP_1: Air area	$0{,}3m^2$	$\pm 0{,}003m^2$
DP_2: Visualization area	50%	±1%	DP_2: Visualization area	50%	±1%
DP_3: Lock	5000cycles	±5%	DP_3: Lock	5000cycles	±5%
DP_4: Inertia	$6{,}25\times10^{-10}m^4$	$\pm4\times10^{-10}m^4$	DP_4: Inertia	$6{,}25\times10^{-10}m^4$	$\pm4\times10^{-10}m^4$
DP_5: Closing force	16,67N	±10%	DP_5: Closing force	25N	±15%



(a) (b)

Figure 6 - Solutions for the problem.

To describe the relationships between each FR and its DPs design matrixes were composed for each solution. In this work, it is necessary to define the equations that describe the behavior of FRs based on DPs. Each design matrix element is then determined by taking the appropriate partial derivatives of these equations, as shown by Eq (8), when the FR_1 is being analyzed.

$$FR_1 = A_{11} \times DP_1 + A_{12} \times DP_2 \tag{8}$$

where A_{11} e A_{12} are determined by Eq (9) and Eq (10).

$$A_{11} = \frac{\partial FR_1}{\partial DP_1}\bigg|_{DP_1=0,05m} = -281{,}372\frac{°C}{m} \tag{9}$$

$$A_{12} = \frac{\partial FR_1}{\partial DP_2}\bigg|_{DP_2=50\%} = 34{,}414°C \tag{10}$$

Keeping the same procedure and extending the analysis for the remaining FRs we get the design matrixes as illustrated in Tab (3).

Table 3 - Design matrixes for solution A and B.

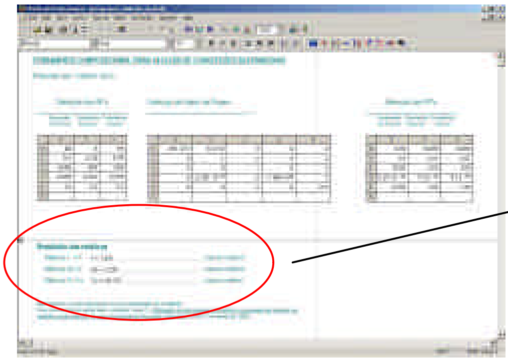
Solution A	Solution B
$\begin{bmatrix} -281{,}372 & 34.414 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & -2.091\times10^{-5} & 0 & -7.964\times10^{6} & 0 \\ 0 & 0 & 0 & 0 & 0{,}6 \end{bmatrix}$	$\begin{bmatrix} 136.884 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & -2.091\times10^{-5} & 0 & -7.964\times10^{6} & 0 \\ 0 & 0 & 0 & 0 & 0{,}4 \end{bmatrix}$

Based on these data, the metrics (*I* and *Ai,* in this case) are calculated through the computational tool that was elaborated, and the values are shown in Fig (7).

For both metrics it is desirable a small value, that is, the smaller the values *I* and *Ai*, the better will be the solution. However, in this case, when taking the metric *I* as decision criteria the solution A should be selected and, when taking the metric *Ai,* as decision criteria, solution B will be the best. But, since both solutions show some functional dependence, in this situation, it is preferable the one that has a higher functional independence level even having a bigger information content. (Sozo, 2002)

Therefore, solution B should be selected. One of the reasons that gives advantage for solution B is that there exist a functional dependence between FR_1 and FR_2 of solution A, that is, when increasing the isolation to get a lower external temperature reduces the satisfaction for FR_2, because the visualization area will be reduced.

Figure 7 - Calculation of metrics through the computational tool elaborated.



	Solution A	Solution B
I	1,291	1,882
Ai	1,232	0,628

6. Conclusions

This work is presented in a form of development and implementation of a decision making process involving axiomatic design approach, applied to the selection of alternative concepts during the product conceptual design phase.

Through a critical analysis of the decision making process involving the selection of alternative concepts, it could be observed that the different existent methods in the literature excel for the clarity and simplicity of the project and, in most cases, they presented as decision critera the project specifications that, logically will be different in each project. Then, it was concluded that there exist criteria and orientations to be followed. However, they are most of the time domain dependents having no set of project specifications that could be used in general for all project areas.

Thus, aiming at solving this lack and reducing the subjectivity level of evaluations, it was performed some researches involving the axiomatic approach. Through a literature review it was possible to identify many contributions of this approach in the design process. Such approach establishes the use of axioms as criteria for decision making. Several authors have been using and researched the axiomatic approach, among them: Harutunian et al (1996), Magrab (1997), Yang & Zhang (2000), Kim & Cochran (2000), Dimarogonas (1993), Marston & Mistree (1997), Ringstad (1997) and etc, illustrating examples and its integration with other theories, resulting in benefits to the product development process. However, there are also authors which contest the application of the axiomatic approach for the whole project areas, mentioning that the design axioms should be treated as two "design rules", among many others, applicable to many cases. In any way, several examples demonstrating the potentiality of this approach were demonstrated and were not found in literature examples being constituted as exceptions to invalidate the axioms.

However, the way that these axioms were defined turned difficult their application in some cases, due to their definition or lack of metrics to measure their meeting. Thus, this might be the main reason for a non uniformity among authors opinion.

Such axioms were then redefined into criteria or goals to be optimized and by the introduction of new metrics it was possible to express their meeting appropriately, providing a broader application to the axiomatic approach. Appropriate criteria were introduced to select coupled and decoupled based on the first axiom. It was also provided the possibility to evaluate coupled and decoupled solutions against the second axiom, task not accomplished by the lack of a suitable metric. These new metrics did exist in literature, but separately. In this work, they were gathered in such a way to form a set of activities having the objective of supporting the decisions to be taken on the decision making process for concept selection, having this as one of the contributions of this work.

Therefore, the main advantages of the decision making process proposed in this work is the reduction of the subjectivity level existent on concept selection, through the use of axioms as criterions to make decision and by mapping the relationships between FRs and DPs. Using the axiomatic approach the team do not have to establish criteria, prioritize them using weights and select the solution by given scores for each one, thus, reducing the subjectivity on design.

Thereby, it was proposed in this work a decision making process for concept selection based on new established metrics, that implemented in a computational tool provides better results for problems that come during the product conceptual design phase.

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